

Although for a long time he did not have a full understanding of how it worked, Lee de Forest invented the triode, or audion as he called it. For nearly half a century it, and its descendants, dominated electronics. De Forest was also one of the earliest inventors of electronic circuits. Justifiably he could claim, therefore, to be one of the founders of electronics. Over 300 patents were filed in his name and many have regarded him as the last of the great individual inventors: but his own hope of a Nobel Prize was never fulfilled.

The name de Forest was of Huguenot origin. Lee's father, Henry Swift de Forest, was a Congregational minister and principal of a school for negroes in Talladega, Alabama. It was there that Lee grew up, having been born in Iowa at Council Bluffs on August 26, 1873. His mother, Anna Margaret Robbins,

Look here, de Forest – you'll never make a telephone engineer...

was the daughter of a Congregational minister.

A wealthy ancestor's endowment of a scholarship at Yale University enabled de Forest to study for a bachelor's degree in mechanical engineering and he was awarded this in 1896. He followed it with a Ph.D. in 1899 for a study of the reflection of electromagnetic (Hertzian) waves from the ends of parallel wires, possibly the first Ph.D. thesis in America on a topic closely related to radio telegraphy.

By the age of 16, de Forest had announced his intention of becoming an inventor. This ambition had not dimmed by the time he left university and he determined to win fame and fortune as an inventor, with Nikola Tesla as his idol. He has also been quoted as saying that Marconi and Edison were his inspiration.

On leaving Yale, de Forest joined Western Electric in Chicago at \$8 a week. But because he was never enthusiastic about working for others it was not long before his interest in radio-telegraphy led him to seek to challenge Marconi, who by then was famous. De Forest wanted his own radio system, independent of Marconi's patents, and his own company. In fact he was to found several companies over the years but he lacked the business skills which



PIONEERS

Lee de Forest (1873-1961):
last of the great inventors?

W.A.ATHERTON

would have enabled any to survive.

At Western Electric his tinkering with radio brought no official acclaim. One day, according to his diary, he was told, "Look here, de Forest. You'll never make a telephone engineer. As far as I'm concerned you can go to hell, in your own way. Do as you damn please."² He took the words literally and worked full time on his own system for the remainder of his fairly short time with the company.

His next employer had built a radio-telegraph receiver which de Forest dismissed as a "non-receiver set"².

In business

With an acquaintance, Smythe, who was also helping to finance him, de Forest filed for a patent in 1900 for a new radio detector which he called a

"responder" and which he hoped would evade Marconi's patents. He then started his first company, bringing in another acquaintance, Freeman. Publicity was gained for their new system, which had a reported range of four miles. Then in 1901 there came the chance to demonstrate his system against Marconi who had contracted to provide ship-to-shore reporting of the America's Cup Yacht races. De Forest's trial has been described as a failure.² During the races he is said to have tossed Freeman's transmitter overboard!

Technically the detector remained de

Above: Lee de Forest (left) in England with John Logie Baird, the pioneer of mechanically-scanned television. This photograph was taken in October 1933.

Forest's big problem. Financially he moved on to bigger things. In 1902 a Wall Street financier helped him start the American de Forest Wireless Telegraph Company, capitalized at \$3M. Smythe and Freeman were left behind.

Early success was achieved with orders from the Army and the Navy and for a radio link between Costa Rica and Panama. But the company's grandiose plans led to its downfall. An American network was envisaged; over 90 stations were erected and others planned, but many never sent a message. Shareholders closed the operation in 1907 and sold its assets. De Forest was forced to resign, taking his patents with him. Amongst other things they covered the, as yet unused, triode.

A strange device like an incandescent lamp...

Immediately the De Forest Radio Telephone Company was formed, with a capital of \$2000 000. Again the Navy bought some equipment, with mixed success. Stock sales staved off bankruptcy and de Forest's talent as a showman maintained publicity. Broadcasts from the Eiffel Tower in 1908 and the first opera broadcast (starring Caruso) in January 1910 kept public awareness alive. Despite making some excellent equipment (the US Navy was its best customer), the company became bankrupt in 1911.

In May 1912, de Forest and his associates were charged with fraud over some of the methods used to promote the company. De Forest was exonerated but two of his colleagues were jailed. The significance of the new technology was not widely understood and the words of the government prosecutor have often been quoted, accusing the defendants of selling stock "in a company incorporated for \$2 000 000, whose only assets were de Forest's patents chiefly directed to a strange device like an incandescent lamp which he called an Audion and which device had proven worthless". That worthless device was the triode.

Towards the triode

The story of the invention of the triode is confused. De Forest's early attempts to design a new detector were frustrated by court cases for infringement of others' patents, e.g. those of Reginald Fessenden. Eventually he returned to

an observation he had made in 1900 that a gas flame dimmed when sparks were generated by his induction coil. This suggested that a gas flame could be used as a radio wave detector. In fact he found that the effect was caused by sound waves from the spark, not radio waves.

Despite that, he maintained a "firm conviction that in the heated gases surrounding incandescent electrodes there must nevertheless exist a response, in some electrical form, to high-frequency electrical oscillations."¹ This conviction led to experiments with electrodes in the flame of a Bunsen burner, and with gas inside a glass bulb ionized by a potential between a cathode and an anode. In this way de Forest started to experiment with thermionic diodes, invented by J.A. Fleming in 1904.

De Forest apparently regarded the ionized gas inside the valve as essential. He wanted an incoming signal to trigger the gas from one conducting state to another, in a manner parallel to that achieved in the popular coherer whose resistance changed dramatically in the presence of electromagnetic waves. It was a long time before he accepted the true explanation of how a vacuum diode worked, based on O.W. Richardson's 1903 explanation of thermionic emission.

So in seeking to cause the trigger effect he wanted in the gas inside the diode, de Forest introduced a third electrode to which he applied the input signal. Although none of the many permutations of shape and size for the third electrode produced a very good detector, he found that the best was an open grid of fine wire. Hence the invention of what we know as the triode. De Forest used the term audion for both diodes and triodes.

Patent battles

Experts seem to differ as to whether de Forest actually began with Fleming's diode and then used the gas flame experiments to try to fight off the accusation of infringing Fleming's patent, or whether de Forest's account is the truth. De Forest was always sensitive to the possibility of a suit for infringement of Fleming's patent, which was owned by the Marconi Company. When the suit did come, Marconi won. Some accept de Forest's explanations of how he made his invention as being the way it was, others see them virtually as disinformation designed to protect himself against this possible suit.

The triode was invented in 1906 and a patent filed in January 1907. De Forest



Lee de Forest, the American inventor whose amplifying device made the transatlantic telephone a practical possibility.

seems to have regarded it as a finished product and did not seek further improvements. He turned his attentions to radio telephony. For years the triode was simply another radio detector, sometimes better, sometimes worse than the more popular crystal or electrolytic detectors.

What transformed the triode into the basis of electronics were the improvements made by industrial laboratories following the discovery of how to use it to amplify and oscillate. These circuit inventions were made independently by several people in 1912 and 1913, de Forest being one of them. The arrival of the amplifier was of great significance to the telephone companies as well as the those involved in radio telegraphy. AT&T bought the repeater rights to the triode for \$50 000 in 1913 and later the radio rights as well.

Lee de Forest: one of the last great individual inventors.

The value of the triode as an oscillator was that it could be used to generate continuous electromagnetic waves for radio transmitters. Four men contested the patent rights to the invention, with de Forest eventually winning the legal battles. The longest patent litigation in American radio history was that between de Forest and Edwin Armstrong³ over the invention of the feedback or regenerative circuit. When Armstrong won the first round in 1917, de Forest sold his patents and any future valve inventions he might make to AT&T for \$250 000. From then on he seemed to lose interest in radio, turning instead to talking pictures. The final legal judgement however went to de Forest, with engineers generally feeling that Armstrong had been let down.

Success

Once the triode had found important uses as an amplifier and oscillator, industrial scientists were quick to understand its mode of operation. De Forest's gas was evacuated to produce a high-vacuum device and a filament life of 1000 hours was achieved in 1913. Oxide-coated filaments increased emission and more new circuits were invented such as the push-pull amplifier (E.H. Colpitts, 1912) and the Colpitts and Hartley oscillators. The First World War provided further stimulus for improvements and use. A somewhat similar path was followed in Europe where Robert von Lieben patented first a diode (1906) and then a triode (1910).

In 1911, when de Forest's company was in severe financial difficulty, he took a job with the Federal Telegraph Company in Palo Alto, California. California then became his home.

Above all, de Forest was a prolific inventor, not a businessman nor a scientist. Amongst his other patented inventions were a high-frequency surgical cautery device, several types of microphones and loudspeakers, and stereoscopic and large-picture television. Naturally he received many medals and decorations but the decision not to award him the Nobel Prize is said to have left him heartbroken⁴. He seems to have had the knack of inspiring intense loyalty in some people, but antipathy in others.

For the last two years of his life illness kept him bedridden, almost totally incapacitated, and financially drained. He died on June 30, 1961, at his home in Hollywood, California, in his 88th year and just four years after his last patent was issued. His fourth wife, Marie, survived him. He was one of the last great individual inventors.

References

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3. W.A. Atherton, *Pioneers* - Edwin Howard Armstrong, *Electronics & Wireless World* November 1987, page 1111.
4. H. Gernsback, *Radio Electronics*, Vol. 22, Sept 1961, p.33.

Next in this series: Grace Hopper - pioneer of computer languages and software.

Tony Atherton is a Principal Lecturer at the IBA Harman Engineering Training College, Seaton, Devon.

My Life with the Printed Circuit, by Paul Eisler, edited with notes by Mari Williams. Dr Eisler's name is hardly a household one, even among engineers, though it certainly deserves to be. For it was he who invented and patented the printed circuit; and indeed in this book he claims to have conceived the integrated circuit too. Yet little thanks did he get for his idea. When he demonstrated a complete radio set built on a PCB to the production director of the Plessey Company in 1936, the invention was rejected.

Apparently Plessey thought it cheaper and more flexible to use girls to wire up its radio sets - a monumentally crass decision in the same league as that of the record company which rejected the Beatles, and one which Plessey deserves to have its nose rubbed in at frequent intervals. But other bodies showed equal thoughtlessness and lack of vision, perhaps the worst being the Government's National Research and Development Corporation. The NRDC more or less gave away Dr Eisler's rights because it did not wish to see UK infringers prosecuted. Even so, Dr Eisler seems surprisingly lacking in bitterness towards his adopted country.

His story is an interesting one. It begins in pre-war Austria, where he was born and attended university; he left because, with a name like his, there was no prospect of employment anywhere in the Nazi sphere of influence. After a bizarre period spent in what is now Yugoslavia, installing radio receivers in express trains (the then equivalent of in-flight entertainment) as an agent of the HMV company, he eventually obtained a job in London as resident technical wizard for the Odeon cinema chain - only to be deprived of it when he was interned by an ungrateful country as a potential Nazi agent.

After struggling on with his printed circuits, which he saw as his personal contribution to military electronics in the fight against Nazi Germany, he progressed to an assortment of other inventions, with varying degrees of success. Packaged foods with built-in heating elements, for the diner in a hurry, may have failed to make the grade (the photographs include a curious picture of a dummy packet of fish-fingers with heating tape folded between the portions), but electric wallpaper for space heating in buildings did more of a better. It would have been still more of a success but for an unexpected national windfall of cheap natural gas from the North Sea, which suddenly made electric heating unattractive.

It is too late to make amends to Dr Eisler for the uphill battles he faced in obtaining his dozens of patents and defending them against the depredations of artful financiers and the unhelpfulness of apathetic bureaucrats. But perhaps we owe it to him to read his book, and to resolve to show just a little foresight should we ever find ourselves in the same position as that man as Plessey.

Associated University Presses (25 Sicilian Avenue, London WC1A 2QH), 170 pages, hard covers, £13.95, ISBN 0-934223-04-1.

MMIC - Monolithic microwave integrated circuits by Yasuo Mitsui (Mitsubishi Electric Corporation). This volume is one of a series of reviews (their subject areas are electronics, computers and communications, manufacturing technology, new materials, and biotechnology) which seek to overcome the language barrier by presenting an accessible English-language account of some aspect of modern Japanese technology. The author presents a survey of MMIC technology (eight Japanese companies, he says, are active in this field) covering manufacturing processes, circuit design and prospects for the future. His text is extensively illustrated with photographs and diagrams, and there is a 148-item reference list at the end. Gordon and Breach Science Publishers, P.O. Box 197, London WC2E 9PX; Harwood Academic Publishers, P.O. Box 786, Cooper Station, New York NY 10276; 127 pages approx. A5, soft covers, \$47, ISBN 2-88124-286-3. This book is also available through the Science and Arts Society, a book club specialising in high-level reference works, at the reduced price of \$34; details from Harwood Academic Publishers.

Lithography in Microelectronics, edited by T.M. Makhviladze: *Proceedings of the Institute of General Physics*, Academy of Sciences of the USSR, Volume 8. This volume contains English-language versions of 11 specialist papers describing Soviet progress in fabricating sub-micron structures. Titles include "Simulation of latent image formation in electron lithography", "Mechanism of nonlinear change in characteristics of positive photoresists upon laser exposure", "X-ray lithography with synchrotron radiation", "Titanium disilicide films for metallization of VLSI circuit connections" and "Theoretical and experimental study of the Josephson Effect in submicron SN-N-NS structures". Published in the US by Nova Science Publishers Inc., 283 Commack Road Suite 300, Commack, New York 11725, 207 pages, hard covers, \$75, ISBN 0-941743-30-6. This material first appeared in Russian in 1987.

Guide to Commercial Telecommunications Services by Jeffrey Hsu. User's introduction to electronic banking, e-mail, teleconferencing and on-line databases: author describes what's on offer and how to gain access to it, with sample on-screen dialogues for many systems. Among the hundreds of sources mentioned in the book - most of them American - are many in the scientific and technical field, including the Institution of Electrical Engineers' Inspec system, described here as "one of the most comprehensive sources on computers, electronics, information systems and technology, and physics". Prentice Hall, 397 pages, soft covers, £26.05, ISBN 0-13-368879-8.